REAL TIME POWER CONTROL STRATEGY FOR OUTPUT POWER FOR SINGLE PHASE INVERTER-LINEAR LOAD

AHMED NAJI ZAIDAN

The project submitted in
Partial fulfilment of the requirement for the award of the
Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
University Tun Hussein Onn Malaysia

JANUARY 2019

I dedicate this thesis firstly to Allah and secondly to my Mother and Father

And whoever fears Allah - He will make for him a way out

And will provide for him from where he does not expect. And whoever relies upon Allah - then He is sufficient for him. Indeed, Allah will accomplish His purpose. Allah has already set for everything a [decreed] extent.

.

(At-Talaq: 1-2)

ACKNOWLEDGEMENT

In the name of **Allah**, The Most Gracious and The Most Merciful, all the praise belongs to Allah, the most Beneficent and Magnificent, who provided me the courage and persistence to conclude this work with successful completion, who was with me in the most difficult times and always.

I would like to thank my supervisor, **Prof. Madya. Shamsul Aizam Zulkifli,** for his valuable suggestions and excellent supervision of this research work during my study.

Many thanks to my committee members (Dr. Asmarashid bin Ponniran, Dr. Rafidah binti Ngadengon) for their helpful comments and careful review of this work.

I would like to take this opportunity to thanks my Gorgeous (father and mother), brother, sisters and my lovely wife and my daughter Lilian for their continuous support and understanding throughout my coursework.

ABSTRACT

Power electronics have been widely used in many applications due to its reliability in controller. This project is to describe and test the real time power control strategy for output power for inverter-linear load connection. The current control strategy was adapted in controlling the output power of inverter to the resistive load. This was done by controlling the output current of the inverter. The output current was controlled by comparing between desired value with the target reference current. The feedback signal from the current output was processed by the microcontroller through the current sensor. The Texas Instrument C2000 microcontroller was used. The justification of this choice was its ability to convert the signal of the current sensor from analog to digital directly from the microcontroller. The controller used was developed from Proportional integral (PI) controller theory using the MATLAB SIMULINK software. At the end, the output power of the inverter was able to control the output current of the inverter as designed. The results obtained reflects a single phase inverter with a controlled output power at the desired value. This is an indication that the output current of inverter was controlled.

ABSTRAK

Elektronik kuasa telah digunakan secara meluas dalam banyak aplikasi kerana kebolehpercayaannya di dalam pengawal. Projek ini adalah untuk menerangkan dan menguji strategi kawalan kuasa masa nyata untuk kuasa keluaran untuk sambungan beban linear-inverter. Strategi kawalan semasa telah digunakan untuk mengawal kuasa output penyongsang kepada beban rintangan. Ini dilakukan dengan mengawal arus output penyongsang. Arus keluaran dikawal dengan membandingkan antara nilai yang dikehendaki dengan arus rujukan sasaran. Isyarat maklum balas dari output semasa diproses oleh mikrokontroler melalui sensor semasa. Alat pengukur mikrokontroler Texas Instrument C2000 digunakan. Justifikasi pilihan ini adalah kemampuannya untuk menukar isyarat sensor semasa dari analog ke digital secara langsung dari mikrokontroler. Pengawal yang digunakan telah dibangunkan daripada teori pengawal integral (PI) yang menggunakan perisian MATLAB SIMULINK. Pada akhirnya, kuasa output penyongsang dapat mengawal arus output penyongsang seperti yang direka. Hasil yang diperoleh mencerminkan inverter fasa tunggal dengan kuasa output terkawal pada nilai yang dikehendaki. Ini adalah petunjuk bahawa arus output penyongsang dikawal.

TABLE OF CONTENTS

LIST OF SYMBOLS AND ABBREVIATION

V	-	Volts
A	-	Ampere
P	-	Proportional
F	-	Farad
H	-	Henry
V_{dc}	-	Direct Current Voltage
V_{ac}	-	Alternating Current Voltage
V_{pk-pk}	-	Peak to Peak Voltage
K_p	-	Proportional constant of PI controller
K_i	-	Integral constant of PI controller
K_d	-	Derivative Constant PID controller
MOSFET	-	Metal-oxide-semiconductor
PWM	-	Pulse Width Modulation
ADC	-	Analogue-to-Digital
DAC	-	Digital-to-Analogue
PID	-	Proportional Integral Derivative
GUI	-	Graphical User Interphase
IGBT	-	Insulated-gate Bipolar Transistor

List of Figures

List of Tables

List of Equation

CHAPTER 1

INTRODUCTION

1.1 Background of project

The quest for better energy generation and utilization is gathering huge momentum globally. There are three major types of electricity generation namely the fossil fuel, nuclear energy, and renewable energy resources. Fossil fuels are known as conventional power generation resources. However, it comes with challenge of releasing multiple harmful gases when they are burnt to generate electricity[1]. The emission of carbon dioxide and sulfur oxides are respectively the main causes of global warming and acid rain[2]. To avoid environmental detriment and meet the increasing energy demand, renewable energy resources such as solar, wind, biomass, hydropower, biofuels, and geothermal are deployed. This has risen the level of researches conducted in this regard. Since renewable energy such as solar energy, fuel cell, wind energy, and hydro energy could be substituted for traditional energy generation resources, extensive research has been done on converting renewable energy into electric energy [3]–[5].

Today, the interest is tilting towards amalgamation of small and medium scale power plants deploying renewable energy sources to form centralized power distribution system. The acceptance and popularity of solar as a form of renewable energy has grown. The use of single-phase voltage source inverter is used to connect the photovoltaic based plants with the output dissemination system. On the other hand, the grid integrated inverter is complex and has strict control measures. For a better flow of power through the solar grids, controller is installed. This usually reduces the fluctuations which characterizes the source prior to injecting it to the grids[6].

Power electronic converters are among important components used in renewable energy source due to its ability to convert the energy from one form to another. The key role this component play is the conversion of DC to AC power as output. During the conversion process, it is important to control the process for qualitative power output. This usually support the delivery of beneficiations attached to the power output. There are many procedures found worthy of using in controlling the output power of the inverter. Prominent among these methods are the voltage and current control strategies. This research adopted the current control strategy.

In this project, a designation of power control flow over inverter connected to the load will be developed. The multi-phase analysis starts with the calculation from the output to determine the values of current and input supply. The selection of value power from output play the main role of representing the whole circuit. Once the power output had been selected, the value of input voltage can be considered to be supplied to the inverter. The mathematical equations actually consist of control loop feedback to make the system a closed loop and controllable. The designation of mathematical equations built into the software are capable of controlling the output of the inverter. These models had contributed to the proper selection of components.

Besides, the designation of mathematical equation is applicable in the sending and receiving of signal from the microcontroller. Next, the signal is then sent to the gate driver to produce voltage and current input to the inverter. In gate driver, the voltage and current are smaller so the power is considered smaller compared to the inverter. In addition, each circuit have its own grounding separately to gain a better grounding effect.

In the meantime, Texas Instruments TMS320F28335 microcontroller was used to control the current at the output. The challenge is the power flow that needs to be controlled. Matlab Simulink is an application that is used to communicate between computer software and the target hardware. The mathematical modelling equations are designed on Matlab Simulink platform. The mathematical models were then downloaded on the microcontroller. The microcontroller has the capability to send and receive signal in the whole circuit. The DC voltage will be sourced as the input of inverter circuit while the output is an AC voltage.

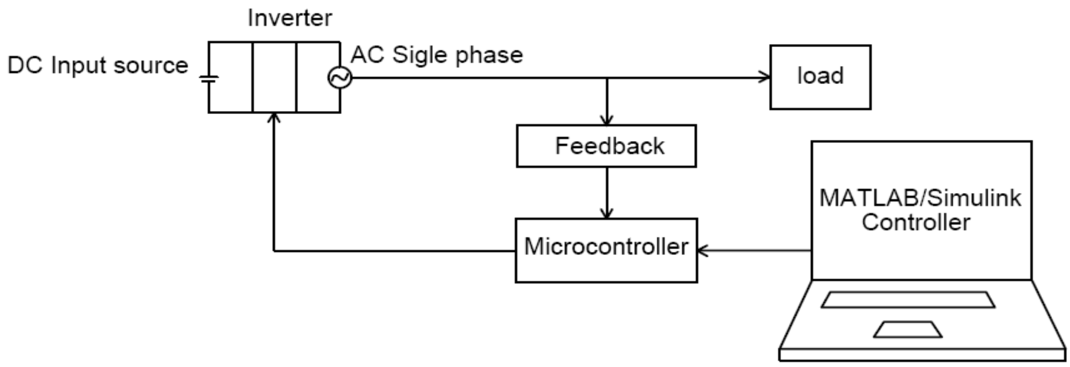

Figure 1.1: Block diagram of the project

1.2 Problem statement

In generation, there are many types of products that are used as inverters. Almost all home appliances and machines are using the inverter. Since there are so many types of different inverter, each of them has limitation in terms of criteria and specifications. However, it important to control the challenges in the inverter for a good output and efficient inverter. Qualitative components are required in order to gain perfect output from inverters. Normally, low quality components are used to reduce the cost of inverter productions sold in the market. This is majorly due to economic reasons. Hence, low quality component causes the output voltage waveform produced to be distortion and increase losses. The factor of losses come from short switching time, high temperature, low quality of filter and high frequency. The simple low pass filter which consist of capacitor and inductor are used in the inverter. These are not capable of smoothening the sinusoidal waveform and control the desired power at output loads.

In highly rated output inverter, higher frequency switching is used to increase the output power, a practice that also increases losses. The increase in losses come from high current in the MOSFET. During ON switching cycle, the value of voltage will be in ‘0’ while the value of current will increase. On the other hand, during OFF switching cycle, the value of voltage output is produced but the value of current decreases. This is an indication that the faster switching frequency affect the value of current. The increases in switching frequency increases the current and cause losses increase. To reduce these losses, certain value of switching frequency needed to be set to maintain the switching frequency at a certain value. The power flow between the inverter has many parameters and challenges that needed to be controlled in order to achieve power flow control. One of such challenges is the harmonic distortion which results due to the nonlinearity of the load, voltage or current surge and current stress.

From the foregoing, the implementation of a power control strategy in the development of a single-phase inverter using MATLAB-Simulink Software gives more reliable opportunity for modification and improvement on the design and control of the inverter. In addition, the development of the single-phase inverter in Simulink adopted the form of a block diagram or Simulink model. This process require a proper design of Mathematical formula of the single phase controller to construct the Simulink model inside the TI (C2000). This design will support power control in the inverter by controlling the power switch of the inverter. This power switch controlled by PWM technique in turn is controlled by PI controller based on the aforementioned design.

1.3 Objective of project

The objectives of the project are:

1. To develop a power control strategy for inverter resistive load using current PI control.
2. To test the modified power control in linear inverter load in simulation mode.
3. To collect the results from hardware setup and compare with the simulation results.

1.4 Scopes of the project

The purpose of this project is to design a power control system for single phase inverter with the aim of controlling the output power of the inverter. The research is separated into two major parts. The first is the design of the system using Matlab Simulink software. The second part is the use of hardware, the PI controller was developed inside the microcontroller TMS320F28335.

The scopes of the project are;

1. Communicate Texas Instruments TMS320F28335 microcontroller with MATLAB-Simulink Software.
2. Design single phase inverter with 10V dc input and 10 Ω ohm linear loads to test the controller
3. Design the PI controller to control the output power of inverter across the linear load by controlling the output current of the inverter. The controller was designed using the feedback signal through current sensor ACS712-5A.
4. The Matlab-simulation of controller develop inside TI through Code composer studio V5 program.

1.5 Outline of the project

In this project, **chapter** 1 discussed the background of the single phase inverter and power control strategy. The problem statement was also highlighted. The chapter concluded by listing the objectives and scope of the research. In **chapter** 2, relevant literature reviewed was explained in relation to the function of the control strategy of the inverter output power. The power inverter, a Matlab software and C2000 Texas instrument microcontroller TMS320F2833 were also explained. In **chapter** 3, the methodology used for the project was discussed. Here, flow charts of the project, hardware setup and flowchart were designed and explained. The chapter further outlined the design specifications was designed and demonstrated. In **chapter** 4 the results of software and hardware were presented and discussed. Finally, in **chapter** 5 the conclusion and recommendation were presented and explained.

1.6 Summary

In this chapter the background of power electronic and how it was important in renewable energy was mentioned and also the control strategy of output power of inverter explained. Problem statement, objective and scope were also mentioned and explained.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, attention will be focusing on previous technical studies, facts and research projects related to this project. The review concentrated on five key topics which include power control strategy, single-phase inverter, power inverter, Matlab software and C2000 Texas instrument microcontroller TMS320F28335.

2.2 Previous projects related to power control strategy for power flow in inverter load-connection

2.2.1 Current control strategies for single phase grid integrated inverters for photovoltaic applications-a review

Today, there are several power control strategies that uses the current control systems for tying single phase grid inverters [7]–[9]. Much as these techniques are numerous, each of the method adopted has both sides of a coin. The analysis of these features requires the design engineer to implement the suitable control mechanism a system. In all, the relevant and prominent control strategies are; proportional integral current control (PICC), proportional resonant current control (PRCC), current hysteresis control (CHC), dead beat current control (DBCC) and model predictive current control (MPCC). The study conducted concentrated on design and analysis of a grid tied single phase VSI (voltage phase inverter) [6]. The result of comparing the performance of current controllers during steady state and transient state was shown in the same study.

The Current control system structure for single phase grid integrated inverter can be seen in schematic diagram of single phase grid tied VSI as shown in Figure 2.1. It consists of four insulated gate bipolar transistors (IGBTs) arranged in H-bridge configuration with each (IGBTs) having a Switch (S) that controls the IGBT switch to “on and off”. The VSI (voltage phase inverter) is connected to the grid through a filter inductor L with an internal resistance R.

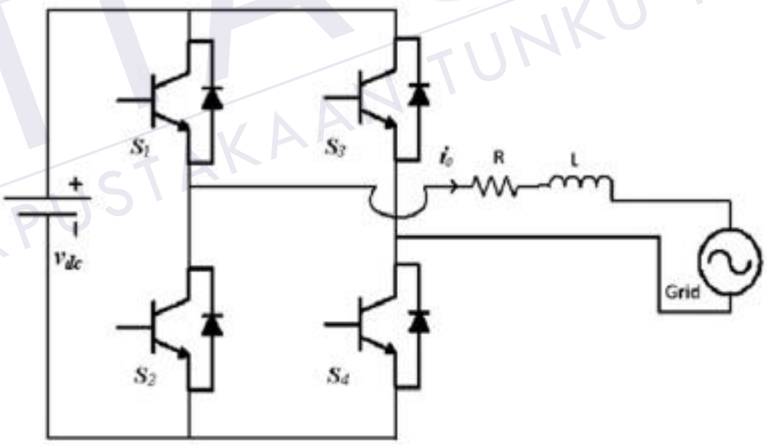

Figure 2.1: Schematic diagram of single phase grid-tied inverter[6].

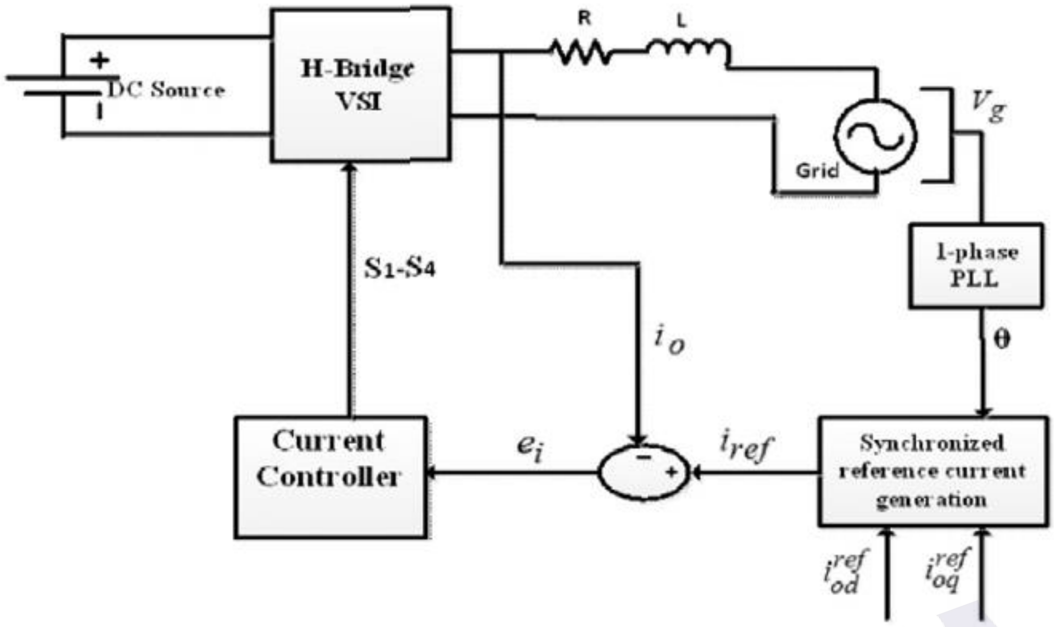

Figure 2.2: Block diagram of current control system[6].

Figure 2.2 represent the current control system in block diagram. The control system regulates the output current delivered by the inverter. This current is then injected into the grid. It function in administering the power conversation between distribution generator (DG) plant and the grid. The power interchange among the grid and the plant is controlled by decoupling control of active and reactive currents. The implication is that in order to design and implement a controller for single phase circuits, it is important to have two signals orthogonal to each other. The role of these signals is for the control of the active power and control the reactive power respectively. In this design, the DC source voltage is held constant while the reference active and reactive currents are both user input command. The single phase PLL (phase locked loop) was used to extract the phase and frequency information of grid voltage. The extracted information is essential to create the reference current signal synchronized with the grid voltage. The measured inverter output current is compared with the reference current and the error is processed by the current controller. The result is then used in generating switching pulses used in the inverter to minimize the error.

For the purpose of this experiment, I_{od}^{ref} and I_{oq}^{ref} are the active and reactive current references responsible for the regulation of the active and reactive power of the system, respectively. The current controller senses the inverter output current and compare it with the reference current. The difference in for of error is then processed by the controller. This component generates switching signals for the inverter to make the current error minimum.

2.2.2 Reactive Power Injection Strategies for Single-Phase Photovoltaic Systems Considering Grid Requirements

Chances are high that there will be a change in policy direction of grid integration in order to accommodate more PV systems into the grid. This was projected on the basis of the increase in acceptance level and installations of photovoltaic systems witnessed lately. In the future, PV systems will be a critical player in the grid regulation policies when the penetration increases reasonably. Some countries are today using the supplementary services such as Low-Voltage Ride-Through. This technology is associated with reactive current injection and voltage support through reactive power control. The future generation systems may focus more on advanced features with enhanced features that improved efficiency and reliability. This will also attract more uses of the PV systems. From the foregoing, Reactive Power Injection (RPI) approaches with emphasis on single-phase PV systems will be considered. This strategy has an edge in the area of delivering a) constant average active power control, b) constant active current control, c) constant peak current control and d) thermal optimized control strategy. These strategies are in compliance with expected active grid codes, with different objectives. In the study conducted by [12], the thermal optimized control strategy was validated using a 3kW single-phase PV system by simulations. The study verified other three RPI strategies using experimental settings on 1 kW singe-phase system in Low-Voltage Ride-Through (LVRT) operation mode. The research revealed the efficacy and possibilities of the suggested strategies with reactive power control during Low-Voltage Ride-Through (LVRT) process.

On the control of power for single phase systems, it was observed that the PV systems were commonly used in residential applications at present. This made the single-phase topologies to be a common solution in the PV systems. Figure 2.3 represents a simple PV solution linked to the grid with the use of a string inverter. The presentation in Figure 2.3, may differ when a DC to DC converter is implemented to improve on the PV panel voltage within an acceptable range of the PV inverter [10],[11],[12]. This system also offers the chances of maxim power point tracking (MPPT) control. The MPPT has been seen as basic requirement for most systems operating at unity power factor. It should be noted that, the injected current need to be harmonized with the grid voltage to ensure compatibility. The I_g and V_g it presented the current and voltage respectively of the Grid that got from inverter. from these two signals the real power P and reactive power Q was calculated and used as feedback signal to the system. After the voltage converted from DC to DC for boosted the voltage stored in capacitor C_{dc} this voltage is V_{dc}. The V_{dc} was been input to the inverter. All these parameters were monitored and controlled for control the injected current recurred to grid for power flow control.

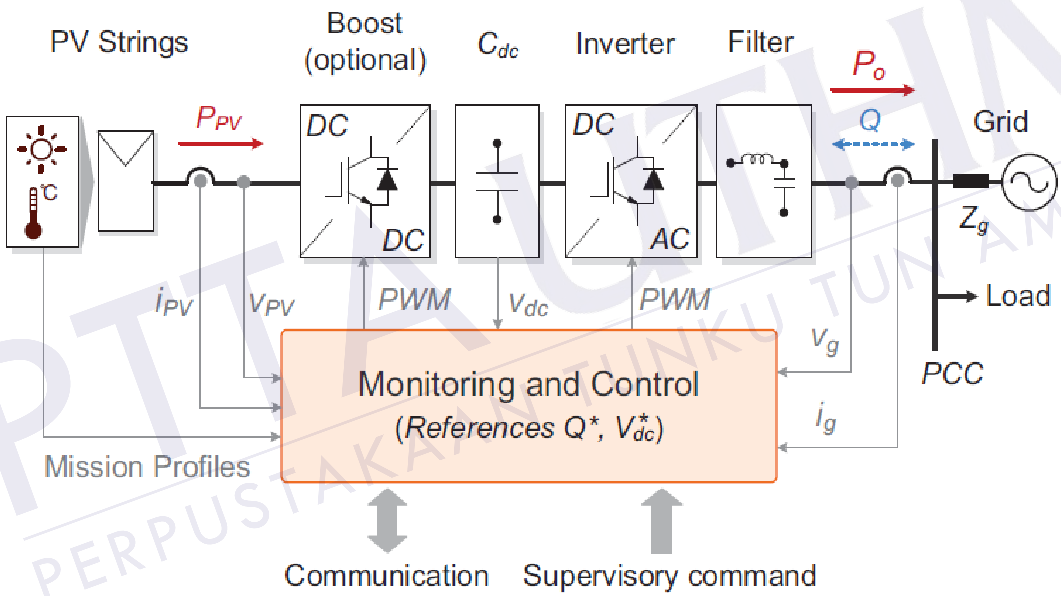

Figure 2.3: Typical power and control configuration of a single-phase grid-connected PV system[4].

Furthermore, in case the system is not compactible, such that it disrupts the frequency or there are voltage differences, it should be disconnected from the grid at the Point of Common Coupling (PCC) as shown in Figure 2.3.

This study explores the Reactive Power Injection Strategies (RPIS) with focus on single phase PV systems. Attention was also given to grid requirements to avoid disturbances. The proposed RPIS include constant average active power control, constant active current control, constant peak current control, and thermal optimized reactive power control strategy. The aim is to improve the reliability during LVRT

REFERENCE

[1] M. H. Rashid, *Power electronics handbook*. Butterworth-Heinemann, 2017.

[2] D. Dong, “Modeling and Control Design of a Bidirectional PWM Converter for Single-phase Energy Systems,” *Response*, pp. 1–114, 2009.

[3] M. Monfared, S. Golestan, and J. M. Guerrero, “Analysis, design, and experimental verification of a synchronous reference frame voltage control for single-phase inverters,” *IEEE Trans. Ind. Electron.*, vol. 61, no. 1, pp. 258–269, 2014.

[4] Y. Yang, I. S. Member, H. Wang, I. Member, F. Blaabjerg, and I. Fellow, “Reactive Power Injection Strategies for Single-Phase Photovoltaic Systems Considering Grid Requirements,” pp. 371–378, 2014.

[5] S. Adhikari and F. Li, “Coordinated V-f and P-Q control of solar photovoltaic generators with MPPT and battery storage in microgrids,” *IEEE Trans. Smart Grid*, vol. 5, no. 3, pp. 1270–1281, 2014.

[6] A. Chatterjee and K. B. Mohanty, “Current control strategies for single phase grid integrated inverters for photovoltaic applications-a review,” *Renew. Sustain. Energy Rev.*, vol. 92, no. April, pp. 554–569, 2018.

[7] R. P, R. I. Vais, S. Yadav, and P. Swarup, “A Modified PI Control for Grid-tied Inverters to Improve Grid Injected Current Quality,” *Int. J. Eng. Technol.*, vol. 9, no. 3S, pp. 529–534, 2017.

[8] N. A. Rahim, J. Selvaraj, and Krismadinata, “Hysteresis current control and sensorless MPPT for grid-connected photovoltaic systems,” *IEEE Int. Symp. Ind. Electron.*, pp. 572–577, 2007.

[9] M. Monfared and S. Golestan, “Control strategies for single-phase grid integration of small-scale renewable energy sources: A review,” *Renew. Sustain. Energy Rev.*, vol. 16, no. 7, pp. 4982–4993, 2012.

[10] Y. Yang and F. Blaabjerg, “Overview of single-phase grid-connected photovoltaic systems,” *Renew. Energy Devices Syst. with Simulations*

MATLAB ANSYS, pp. 41–66, 2017.

[11] L. Nousiainen, *Issues on Analysis and Design of Single-Phase Grid-Connected Photovoltaic Inverters*, vol. 1087, no. 2012. 2012.

[12] R. Alsharif and M. Odavic, "Photovoltaic generators interfacing a dc micro-grid: design considerations for a double-stage boost power converter system," in *Power Electronics and Applications (EPE'16 ECCE Europe), 2016 18th European Conference on*, 2016, pp. 1–10.

[13] K. Kim, H. J. Kim, D. Shin, J. P. Lee, T. J. Kim, and D. W. Yoo, "A novel seamless transfer control strategy for wide range load," *ECCE 2016 - IEEE Energy Convers. Congr. Expo. Proc.*, pp. 1–5, 2016.

[14] T. V. Tran, T. W. Chun, H. H. Lee, H. G. Kim, and E. C. Nho, "PLL-based seamless transfer control between grid-connected and islanding modes in grid-connected inverters," *IEEE Trans. Power Electron.*, vol. 29, no. 10, pp. 5218–5228, 2014.

[15] Y. Chen *et al.*, "Seamless transfer control strategy for three-phase inverter in microgrid," in *Power Electronics and Motion Control Conference (IPEMC-ECCE Asia), 2016 IEEE 8th International*, 2016, pp. 1759–1763.

[16] B.-J. Kim, J.-H. Cho, J.-M. Kim, J.-H. Lee, and C.-Y. Won, "An enhanced control strategy for seamless transfer of grid-connected single-phase inverter in synchronous rotating frame," in *Electrical Machines and Systems (ICEMS), 2017 20th International Conference on*, 2017, pp. 1–6.

[17] M. D. Singh, *Power electronics*. Tata McGraw-Hill Education, 2008.

[18] *B.D Bedford, R.G.Hoft. Principle of Inverter Circuits. New York, John Wiley &Sons, 1964.* .

[19] N. Mohan and T. M. Undeland, *Power electronics: converters, applications, and design*. John Wiley & Sons, 2007.

[20] D. Chen, X. Li, R. Zhang, and H. Zhang, "Combined three-phase inverters with high frequency pulse DC link," in *PESC Record - IEEE Annual Power Electronics Specialists Conference*, 2005, vol. 2005, pp. 835–841.

[21] A. Ahmed, *Power Electronics for Technology*. Prentice Hall, 1999.

[22] A. Jain *et al.*, "Porous silica materials as low-k dielectrics for electronic and optical interconnects," *Thin Solid Films*, vol. 398, pp. 513–522, 2001.

[23] M. A. T. M. Yusof, “Development of Inverter Controller for BLDC Motor using PIC16F877A,” Universiti Tun Hussein Onn Malaysia, 2012.

[24] W. K. Wong, “Development of PWM Inverter Educational Board,” Universiti Tun Hussein Onn Malaysia, 2012.

[25] T. C. A. Ajot, S. Salimin, and R. Aziz, “Application of PI Current Controller in Single Phase Inverter System Connected to Non Linear Load,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 226, no. 1, 2017.

[26] “http://www.ti.com/.” .

[27] “www.mathworks.com.” .

[28] T. I. Incorporated, “Texas Instruments Incorporated - Second-Stage LC Filter Design,” *Texas Instruments Inc.*, no. July, pp. 8–10, 2000.